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REPORT

Two audio test-signal generators for assessing programme-modulated noise in digital compandors

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Summary

Certain forms of programme-quality impairment are, at present, best investigated subjectively. Natural sounds cannot be repeated precisely without using a recording process which may itself introduce some impairment, so their use as test signals for subjective investigations is somewhat limited. Synthetic signals, generated electronically, are attractive since a searching test-pattern can be repeated indefinitely without the use of a recording process.

This Report describes two experimental generators which provide test signals intended principally for the investigation of programme-modulated noise in digital compandors. The forms of the test signals are such as to stimulate this effect with minimal masking of any impairment produced.

One of the generators gives a sequence of notes in analogue form. The notes are musical in character, not untypical of real programme; any effects from programme-modulated noise introduced by equipment under test are therefore similar in character to those produced under normal programme conditions, but they are revealed repeatedly and more clearly. The test signal is therefore appropriate for conventional subjective testing, and, though originally used to assess digital equipment, is equally applicable to analogue system testing.

The second generator provides a test signal in digital form. Transmitted by a perfect digital system this test signal produces virtually no sound at the output. When processed by a digital system likely to produce programme-modulated noise, however, audible tones are generated which vary with the degree of imperfection of the system. The digital test signal is a powerful diagnostic tool for the engineer who is, say, setting up digital equipment or comparing two such items of equipment. However, since it is totally unlike normal programme and, further, since programme-modulated noise is revealed in stylised form, the test signal is not suitable for conventional subjective testing.

Issued under the authority of

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1. Introduction

The characteristics of sound-signal equipment can generally be measured and specified objectively, but the correlation of measured data with the subjective assessment of performance is not always good. Recent work has improved the latter situation for certain defects; for example Geddes[1] and Belcher[2] have indicated ways of improving the agreement between objective measurement and subjective assessment for noise and for waveform distortion respectively. However, some forms of impairment remain which, at present, normally require subjective assessment. Perhaps the best known of these is the so-called 'hush-hush' effect due to programme-modulated noise.* This effect is often associated with sound-signal companding systems, both digital and analogue.

Selected passages of solo piano music have been found to be among the most critical test material for evaluating programme-modulated noise subjectively and, in recorded form, have been widely used for this purpose. Unfortunately, the recording process itself often introduces a measure of programme-modulated noise which tends to confuse the assessment of the apparatus under investigation. Live piano music, even if it could be readily provided, would not be entirely suitable because of the difficulty of achieving repeated presentations, identical both in character and in level, as required for subjective tests.

Synthetic test signals, generated electronically, are attractive since a given test sequence can be repeated precisely for as long as is required. Further, no recording process is involved, so the test signals are, to that extent, 'live' and are virtually free from added noise and distortion.

Two experimental synthetic test-signal generators have recently been constructed, primarily to enable the performance of sound-signal digital compandors to be more easily assessed. These generators are described below.

2. General properties of the test-signal generators

The optimum form of a test signal depends on the nature of the impairment it is intended to reveal. It should be such as to explore the conditions under which the apparatus being tested is most likely to produce that impairment. It should, further, cause minimal masking of the impairment. The latter can be achieved by arranging the test signal to be different in character from the impairment being studied or to be inaudible. The two generators described in this Report produce signals which vary in level in a predictable and repeatable manner.

One, commonly known as the 'electronic gong', produces a sequence of 'notes' with an envelope shape which rises smoothly from zero to a maximum value and returns smoothly to zero. This signal can be arranged to explore the most critical range of levels for the apparatus under test and, by virtue of its simple form, it is unlikely to conceal any impairment products which may be produced. Subjectively, the signal is musical in character, not untypical of 'real' programme material, and it is thus suitable for use in subjective testing. The electronic gong can be applied to testing both digital and analogue audio equipment. A particularly stringent test can be made by using high-pass filtering to remove the fundamental component of the output signal from the equipment under test; what is left behind consists only of unwanted noise and distortion introduced by the equipment. This technique has proved particularly useful for assessing and aligning digital codecs, for which quantising noise, granular distortion and programme modulated noise are thus fully exposed.

The second generator provides a simple digital test signal, corresponding to a triangular baseband signal, which can be arranged to explore fully the dynamic range of the digital processing device under test. The fundamental frequency of the baseband signal is made so low that the signal is virtually inaudible, while the effects of programme-modulated noise show up as higher frequency tones. This test signal is particularly useful for comparing two digital compandors quantitatively but it is not suitable for conventional subjective testing. It has additional uses for investigating non-linearities in digital-to-analogue converters.

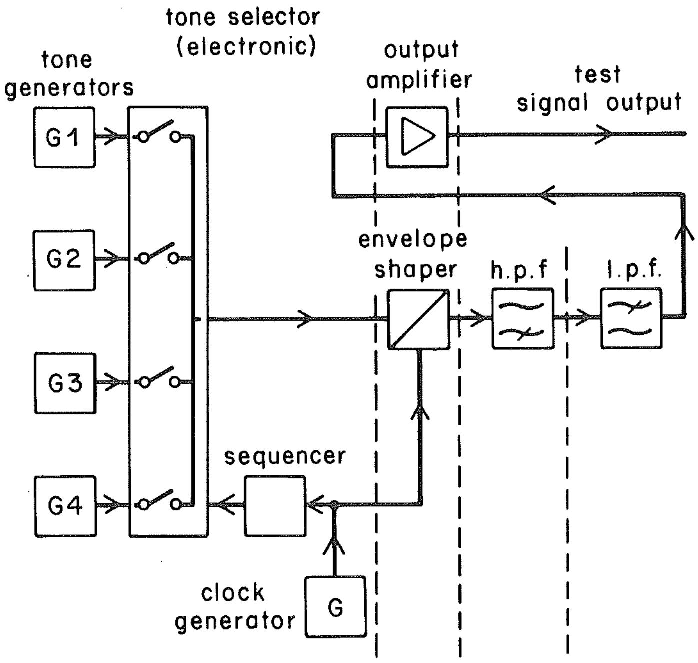

Fig. 1 - Electronic gong: block schematic

* Programme-modulated noise is noise whose amplitude depends on programme amplitude.

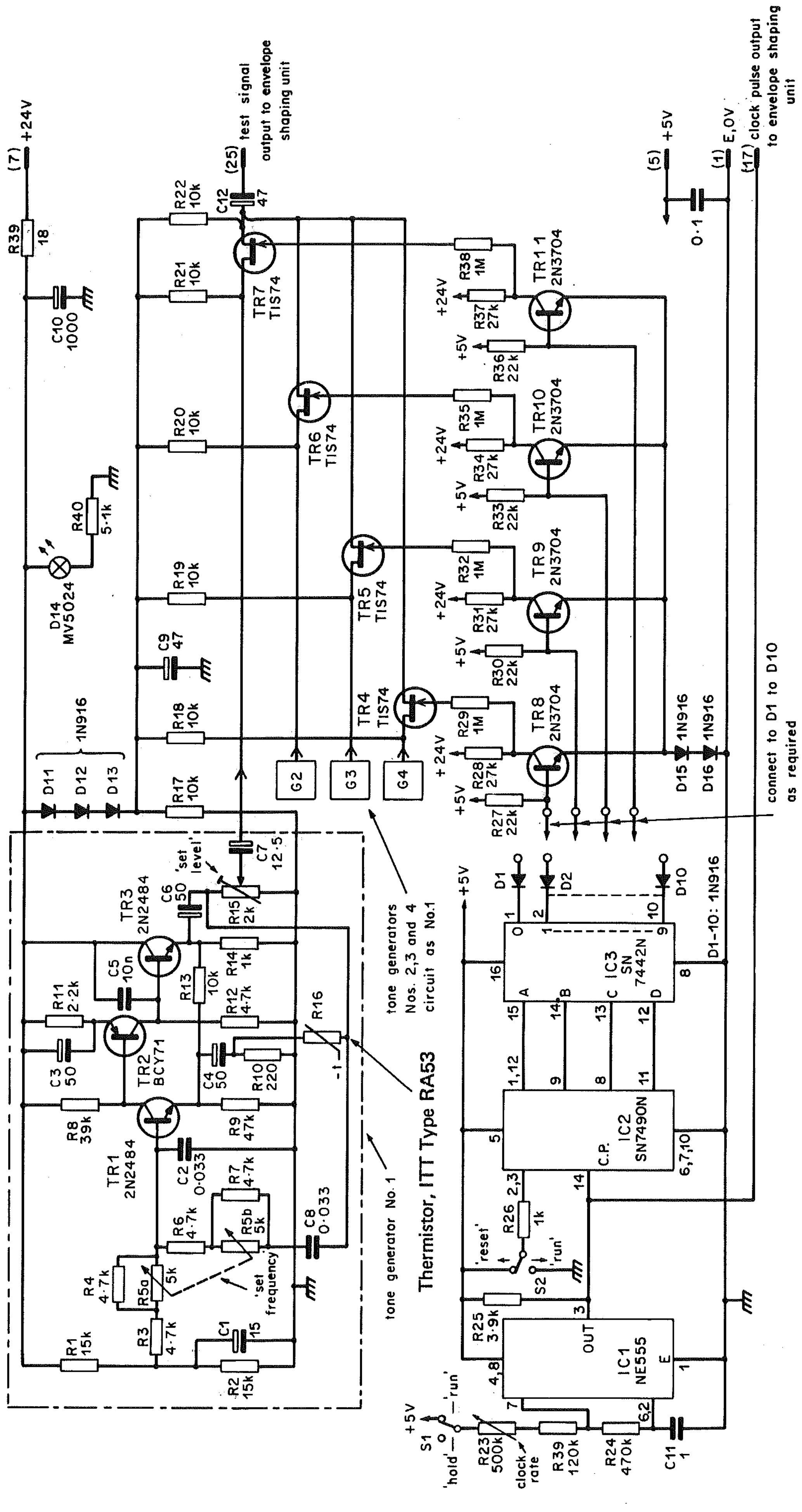

Fig. 2 - Electronic gong: circuit of tone generators, clock pulse generator and sequencer

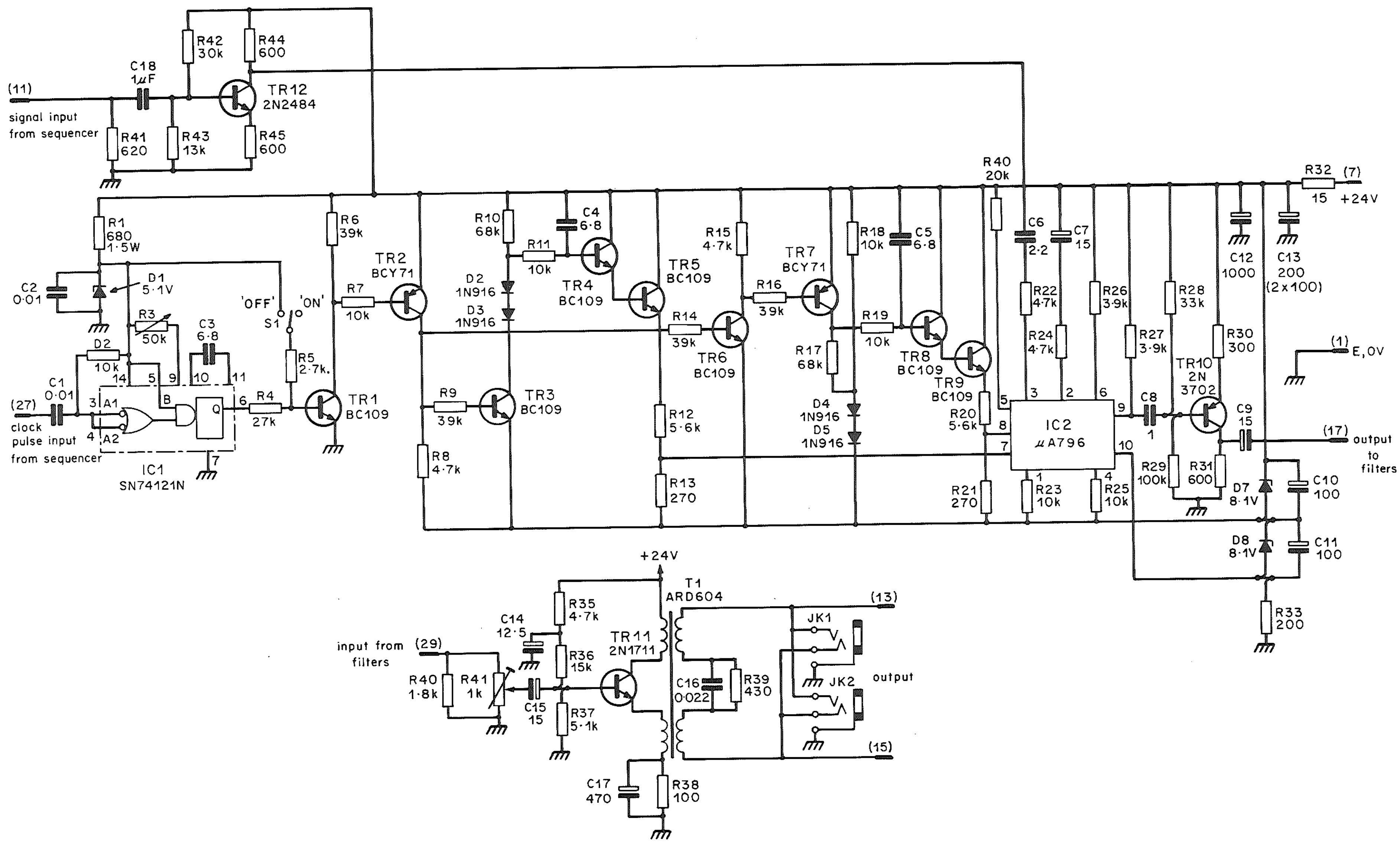

Fig. 3 - Electronic gong: circuit of envelope shaping unit and output amplifier

3. Electronic gong

3.1. General circuit arrangement

Fig. 1 shows the circuit arrangement of the experimental electronic gong in block schematic form. The apparatus comprises essentially four tone generators whose outputs are switched, in a pre-set pattern and at a pre-set rate, to an envelope shaper and thence, through low-pass and high-pass filters, to an output amplifier. For convenience the experimental apparatus was assembled in four units. Unit one carries the tone generators, the selector switches, a clock generator and a sequencer. Unit two carries the envelope shaper and the output amplifier. Units three and four carry the high-pass and low-pass filters respectively.

3.2. Generator/sequencer unit

Unit one consists of the tone generators and the tone sequence switching, controlled by an internal clock generator. The circuit is given in Fig. 2.

The circuit of one of the four identical tone generators is shown in detail. It comprises a three-transistor RC oscillator, TR1, TR2 and TR3. Two pre-set controls are provided. One is a two-gang variable resistor R5A/R5B to allow the frequency of oscillation to be set within the range from about 500 Hz to 1 kHz. The other, R15, sets the output level as required. Each tone generator output is applied to one of four series field-effect transistor (FET) selector switches, TR4 to TR7. Each FET is controlled by an associated driver transistor (TR8 to TR11), so that any of the generated tones can be routed to the unit output. The signal at the output of the unit comprises steady sinusoids, switched abruptly in a pre-set pattern, between up to four frequencies.

Timing of the tone-switching operation is determined by the clock generator, IC1, and its associated components. Control of the clock rate is provided by variable resistor R23. Clock pulses are applied to the sequencer circuit which comprises a decade counter, IC2, and a four-line to ten-line decoder, IC3. The ten outputs of IC3 are taken, via diodes D1 to D10, to pins on the printed-circuit board. Connections from these pins to the four base connections of the selector-switch driver transistors TR8 to TR11, are made by flying leads. Any selector switch may be operated repeatedly as required, simply by connecting the base of the driver transistor to the appropriate diode output from the sequencer. Any ten-note sequence of the four notes provided can be produced as desired by appropriate flying-lead connections.

Two switches, S1 and S2, allow operation to be stopped at any time. S1 holds the sequence at the point of interruption, while S2 resets the counter to the sequence-start condition.

3.3. Envelope shaper and output amplifier unit

Unit two consists of the envelope shaper and output amplifier. The circuit is shown in Fig. 3. Envelope shaping is achieved by means of a balanced modulator,* IC2, to which the tones from unit one, together with appropriate modulating signals, are applied. The tone signal to be modulated or 'enveloped shaped', is applied to pin 3 of IC2, while complimentary shaping signals are applied to pins 7 and 8. The relative duration of the leading and trailing portions of the shaped envelope (the 'rise' and 'fall' periods) is determined by the rate of change of voltage on capacitors C4 and C5. These voltages are applied to pins 7 and 8 through buffer stages TR4, TR5, TR8 and TR9. During the rise period C4 is charged through R11, and C5 is discharged through R19. During the fall period C4 is discharged through R11 and R10 in series and C5 is charged through R19 and R17 in series. Thus the fall period must be longer than the rise period, but, with this provision, the two may be set substantailly independently by appropriate selection of the resistor values.

Clock pulses from unit one trigger monostable IC1 which, in turn, switches on transistors TR1 and TR2. These, acting through buffer stages TR3, TR6 and TR7, cause C4 to be charged and C5 to be discharged as required for the rise period of the test tone pulse. The length of the rise period is set by the duration of the output pulse from monostable IC1 and can be adjusted by R3. The length of this monostable pulse must be matched to the time constants C4 R11 and C5 R19 which determine the actual rise rate of the envelope of the output test signal. R3 should be adjusted to obtain the optimum envelope shape, judged visually on an oscilloscope display.

At the end of the control pulse from IC1, C4 is discharged and C5 is charged and the output signal envelope falls to zero as described earlier. Fig. 4 shows a typical output envelope shape.**

* This circuit is a slightly modified version of that used in an existing BBC automatic crossfade unit.

** The envelope shape illustrated is not necessarily optimum for any particular form of impairment, but it has been found extremely useful in assessing the performance of digital sound apparatus.

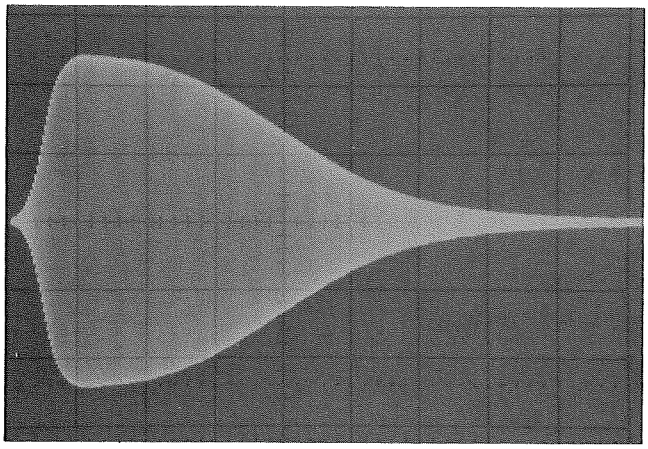

Fig. 4 - Electronic gong: typical output envelope shape, time-base speed 50 ms/major division

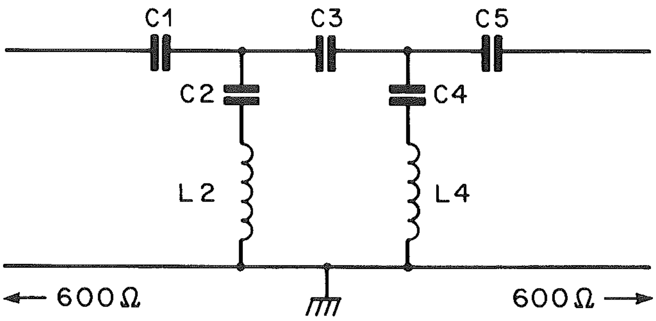

Fig. 5 - Electronic gong: 450 Hz high-pass filter

C1 = 0·488 μF C2 = 7·25 μF C3 = 0·296 μF C4 = 2·65 μF
C5 = 0·543 μF L2 = 148 mH L4 = 167 mH

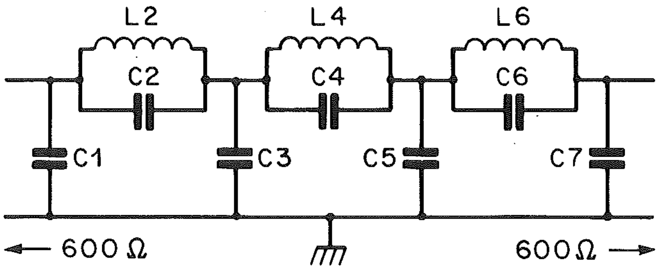

Fig. 6 - Electronic gong: 1 kHz low-pass filter

C1 = 0·369 μF C2 = 0·0389 μF C3 = 0·522 μF
C4 = 0·118 μF C5 = 0·430 μF C6 = 0·231 μF C7 = 0·245 μF
L2 = 114·5 mH L4 = 99·6 mH L6 = 68·05 mH

Switch S1, in the envelope-shaping control circuit, allows the modulator to be disabled, when desired, for test purposes.

Signals from the envelope shaper are taken from unit two to the filters in units three and four, and then returned to the output amplifier in unit two. This amplifier is a single transistor stage providing a 600 ohm floating output from a transformer. A pre-set gain control, R34, allows the output level, nominally +8 dBm, to be set as required.

3.4. Filters

The tone signals from the envelope shaper are passed through high-pass and low-pass filters, Fig. 5 and Fig. 6, respectively, which serve to reduce any distortion, noise or hum introduced in the earlier stages. The filters in the experimental model are cascaded without a buffer stage, and provide a pass-band of about 450 Hz to 1 kHz. Signals below 250 Hz and above 1·25 kHz are reduced by 55 dB or more.

3.5. Performance

Normal maximum output level

+ 8 dBm

Working range of test-tone frequency (with filters provided)

Approximately 600 Hz to 900 Hz.

Clock period

Approx. 750 ms to 1·5 s.

Distortion of oscillators

Typically 0·01% total

Distortion at output, steady-state, with envelope shaper switched off

2nd harmonic, typically 0·025%

3rd harmonic, typically 0·006%

Unwanted signal* at output (with sequencer switched off) (unweighted)

84 dB below maximum signal level (with envelope shaper 'open')
92 dB below maximum signal level (with envelope shaper 'closed')

Breakthrough of unwanted tones

Approximately 66 dB below wanted tone.

4. The digital test signal

4.1. General

This Section describes a simple digitally-generated test signal. Digital compandors produce programme-modulated noise due to coarser quantising of higher amplitude signals. The signal described here has no programme-modulated noise of its own and, when applied to a digital compandor, shows up the programme-modulated noise due to the compandor in a striking way, as high-frequency components in the output signal. The worse the programme-modulated

* Excluding hum from output amplifier at about 66 dB below max. signal level. (Measured with quasi-peak reading test-programme meter.)

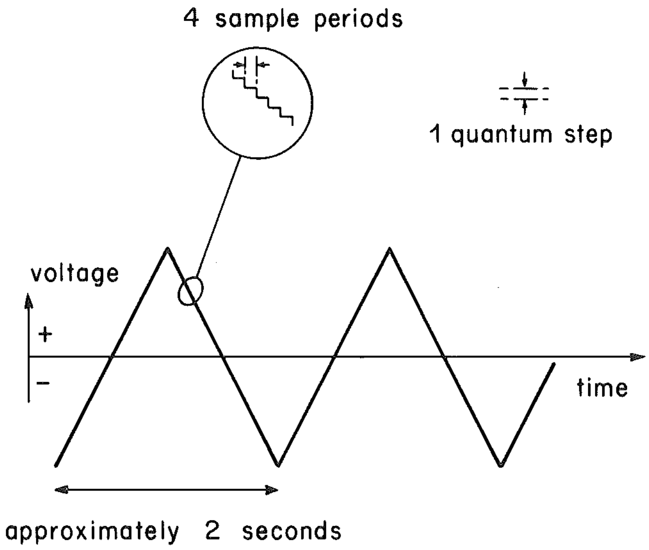

Fig. 7 - The digital test signal, in analogue form

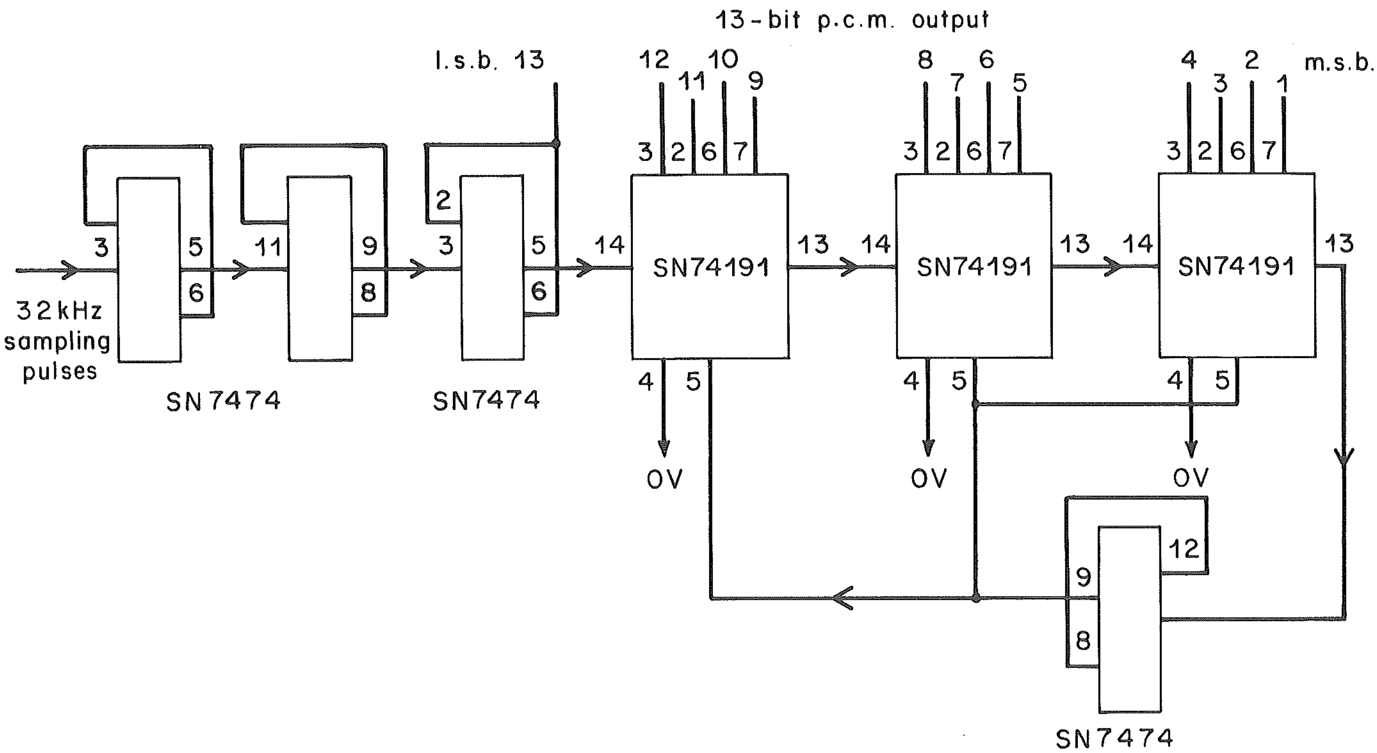

Fig. 8 - The digital triangular-wave generator

noise, the higher is the amplitude and the lower the frequency of these components.

4.2. The test signal

The test signal is a triangular wave in digital form, whose peak-to-peak amplitude is the full conversion range of the digital coding system. When converted to analogue form, the signal is as shown in Fig. 7 and is virtually inaudible since its fundamental frequency is about 0·5 Hz. The signal may be generated in 13-bit offset binary form using the circuit shown in Fig. 8. The all-zeros code represents a large negative signal and the all-ones code represents a large positive signal. A 14-bit signal could be generated if the counter had one extra stage.

The generator is driven by sampling-frequency pulses which are usually 32 kHz for 15 kHz digital sound signals. Each 13-bit number from all zeros to all ones is generated in turn and is present for four sample periods. This means that there is an 8 kHz sawtooth waveform superimposed on the triangular wave. The peak-to-peak amplitude of this waveform is one quantum step.

4.3. The effect of digitally companding the test signal

When the 13-bit digital test signal is passed through a digital compandor, some of the 13-bit numbers are reduced to less than 13-bit accuracy. In the 10-bit near-instantaneous compandor[3,4] this is done by removing least significant bits, as appropriate. In the 10-bit 'A' law[3,4] instantaneous compandor a different 10-bit code is used. In either case, when the input signal is reconstructed, some of the numbers will have been reduced in accuracy.

When the signal is being coded to 12-bit accuracy it will remain on certain quantum levels for 8 sample periods instead of 4 as in the original test form. There are then some quantum levels which will not be present in the output signal. As the signal increases or decreases in level, at 12-bit accuracy, it will jump two quantum levels. Thus at 12-bit accuracy there will be superimposed on the triangular wave a sawtooth whose frequency is 4 kHz and whose peak-to-peak amplitude is two quantum steps. Similarly, when the compandor is producing 11-bit accuracy there will be a sawtooth whose frequency is 2 kHz and whose peak-to-peak amplitude is four quantum steps, etc. These situations are shown in Fig. 9.

Two digital compandors could be compared using this signal. The one which produces the coarser quantising will give a lower frequency, higher amplitude impairment.

Thus, when this digital test signal is applied to the input of a digital compandor, the output of the digital-to-analogue converter (d.a.c.) will contain tones which, unlike most of the test signal itself, fall within the audio passband. When the test signal is digitally companded and the output of the d.a.c. is a.c. coupled to remove the low-frequency triangular wave, the resulting output signal would be similar to that shown in Fig. 10, depending on the digital compandor. This signal is representative of the programme-modulated noise introduced by the digital compandor.

4.4. The advantages of the digital signal

The advantages of the digital signal over programme for testing digital compandors are:

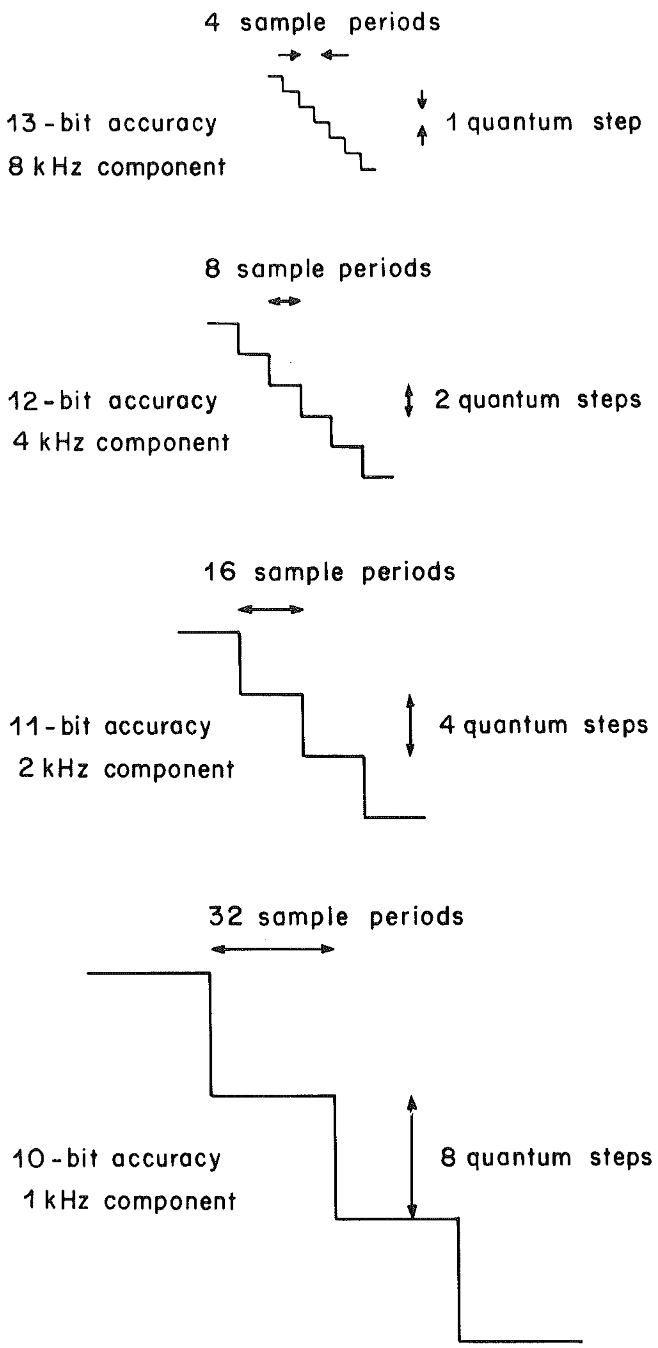

Fig. 9 - The effects of coarsely quantising the test signal

(a) it is exactly reproducable

(b) it is virtually inaudible itself but it produces an audible output, related to programme-modulated noise, when applied to a compandor

(c) it is cheap and easy to make

(d) the test signal generator should need no line-up procedure

(e) it may be used for checking the performance of a (linear) d.a.c. (i.e. if the d.a.c. is working properly there will be no audible output whose peak-to-peak amplitude is greater than one quantum step).

5. Conclusions

Two experimental electronic test-signal generators have been described. These were devised principally to aid the subjective evaluation of programme-modulated noise in digital compandors. One generator produces an analogue test signal, the other a digital test signal.

The two generators have been in use for about a year and have proved valuable aids in development work on digital sound-signal equipment. The analogue test signal is musical in character and is suitable for conventional subjective testing, though it is improbable that it will ever fully displace actual music for this purpose.

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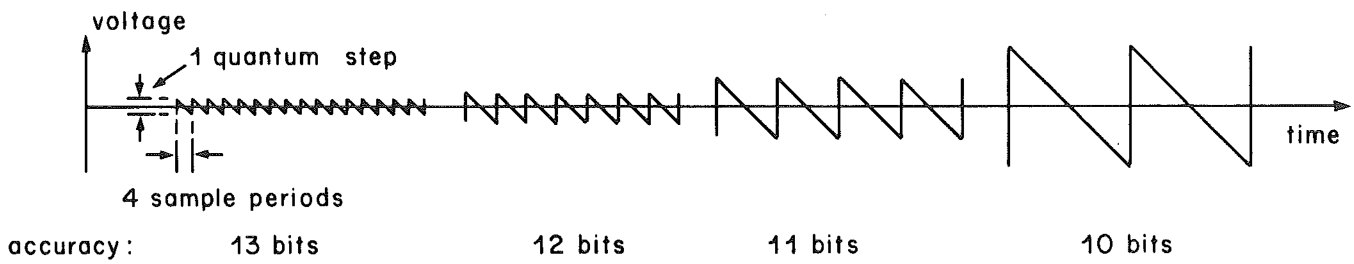

Fig. 10 - The distortion component introduced into the test signal by a digital compandor

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